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(54) **RECEIVER ARCHITECTURE WITH RECONFIGURABLE ON-CHIP MATCHING FOR WIDEBAND OPERATION AND OFF-CHIP MATCHING FOR LOW-POWER OPERATION**

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**H04B 1/00** (2006.01)

(52) **U.S. Cl.**  
CPC ..... **H04B 1/00** (2013.01)

(58) **Field of Classification Search**  
USPC ..... 455/248.1  
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,761,307 B1 \* 6/2014 Ionescu et al. .... 375/316  
2008/0007336 A1 \* 1/2008 Belot et al. .... 330/250

\* cited by examiner

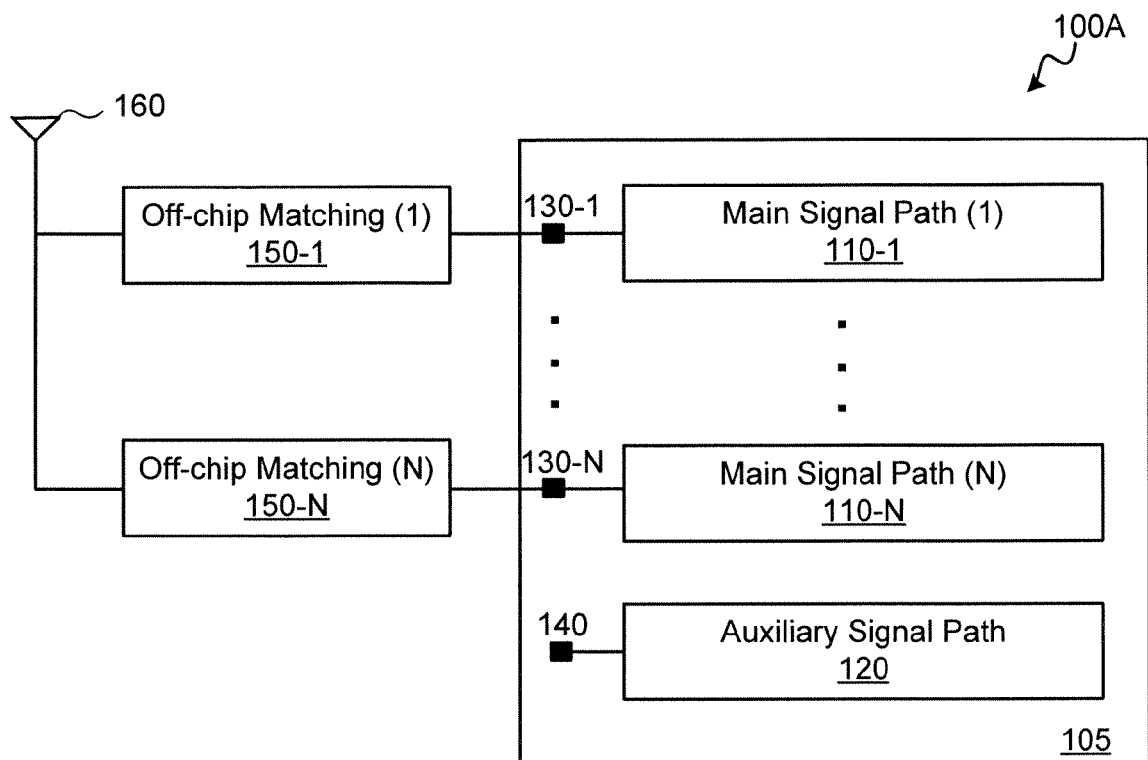
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(57) **ABSTRACT**

A circuit for a receiver with reconfigurable low-power or wideband operation may comprise one or more main signal paths each coupled to a first port and including a low-noise amplifier (LNA) configured to provide a radio frequency (RF) signal to a main mixer circuit. An auxiliary signal path may be coupled to a second port. The auxiliary signal path may include an auxiliary mixer configured to provide an on-chip matching input impedance that may match an impedance of the antenna. The first port may be coupled to an RF antenna through an off-chip matching circuit, when a low-power operation is desired. The first port may be coupled to the second port and to the RF antenna, when a wideband operation is desired.

**18 Claims, 6 Drawing Sheets**



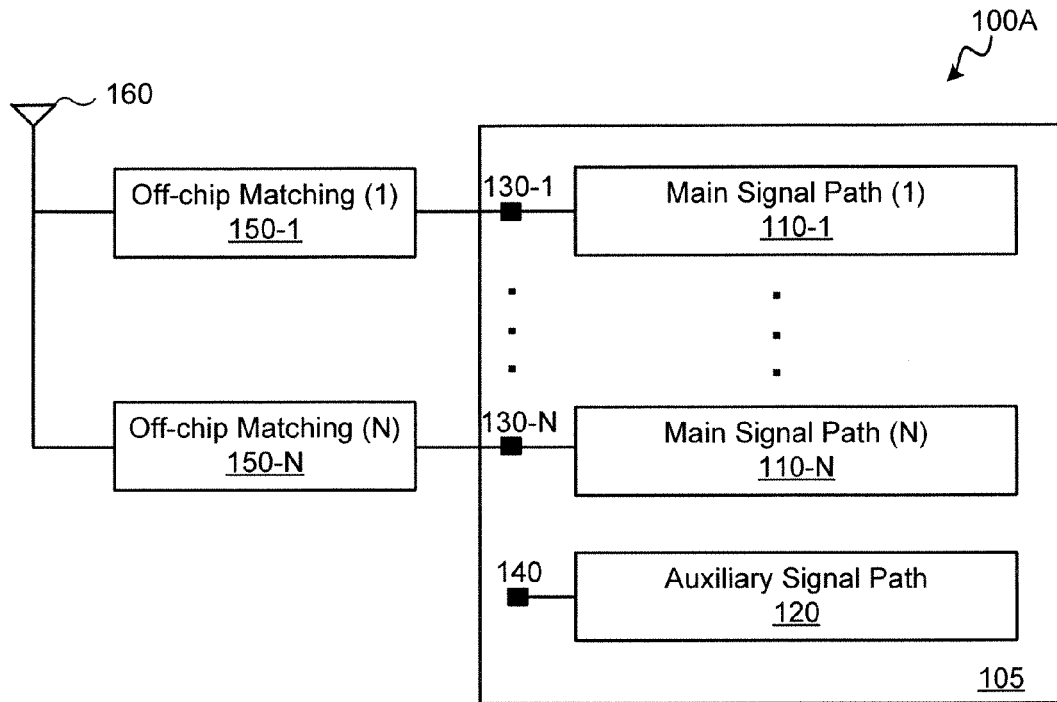


FIG. 1A

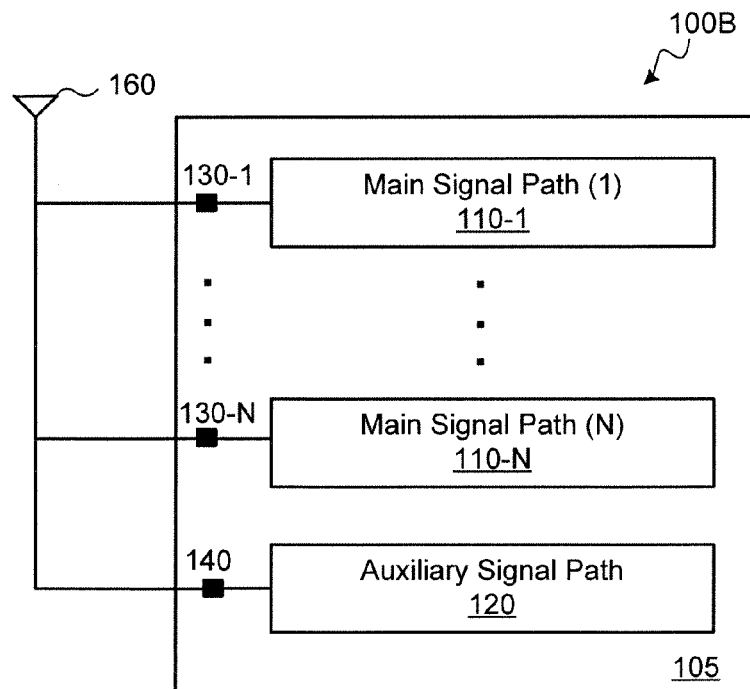


FIG. 1B

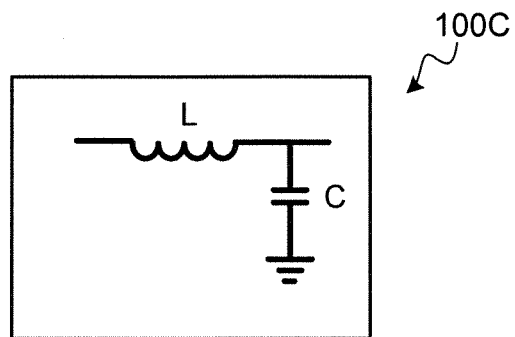


FIG. 1C

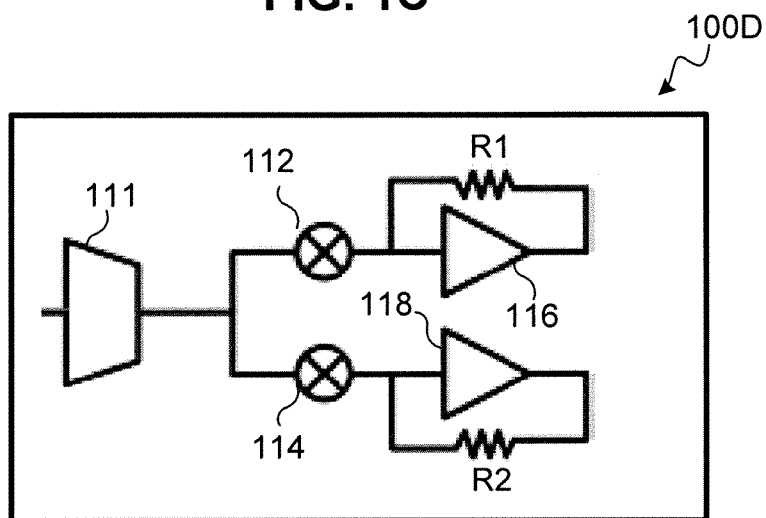


FIG. 1D

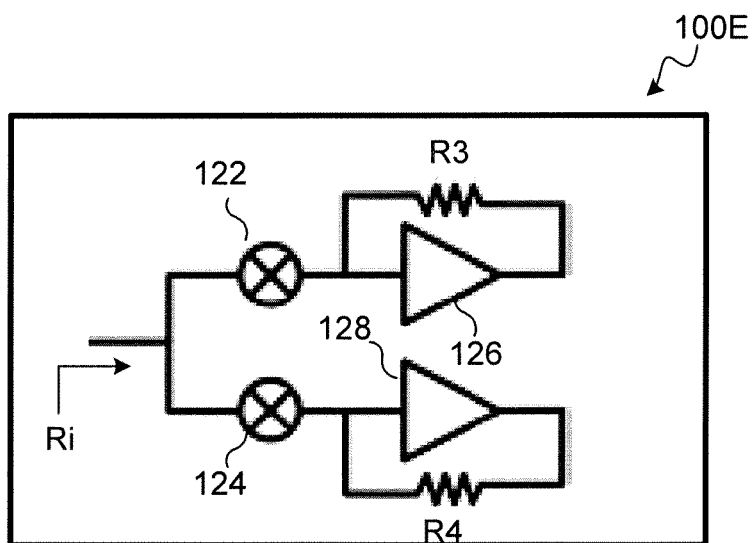


FIG. 1E

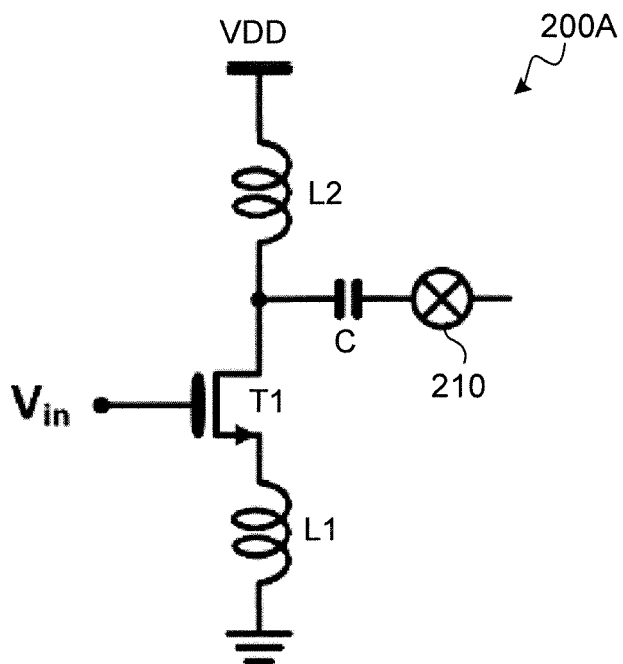


FIG. 2A

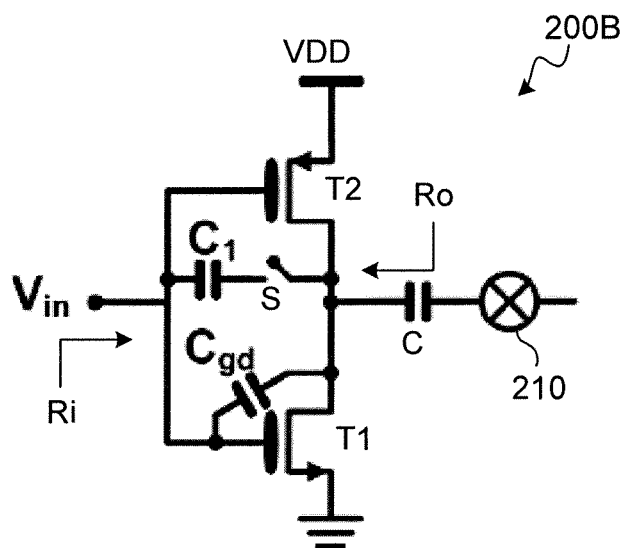


FIG. 2B

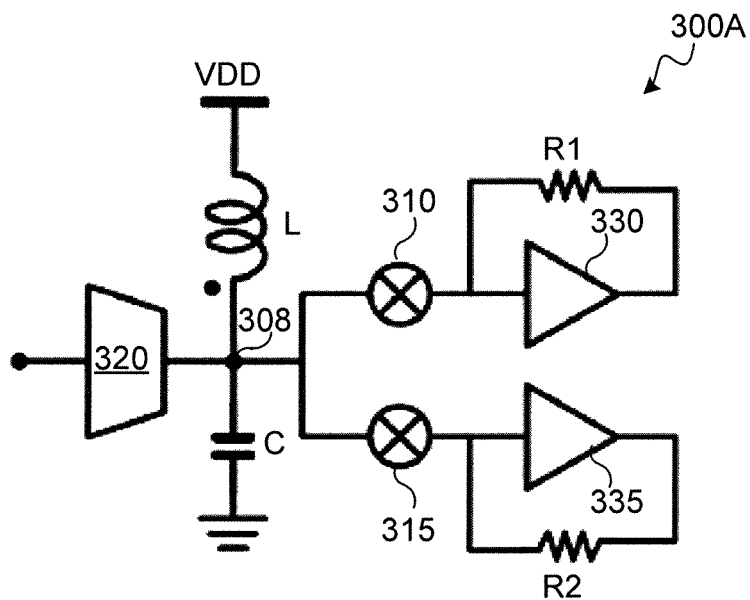


FIG. 3A

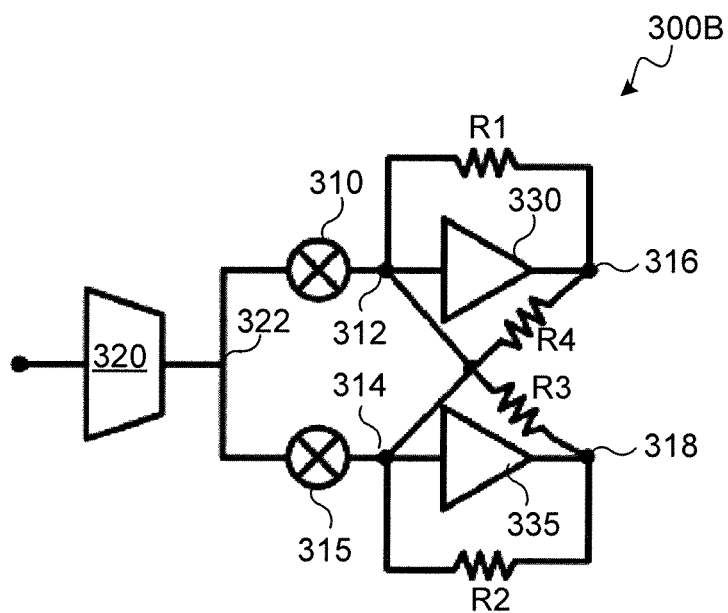
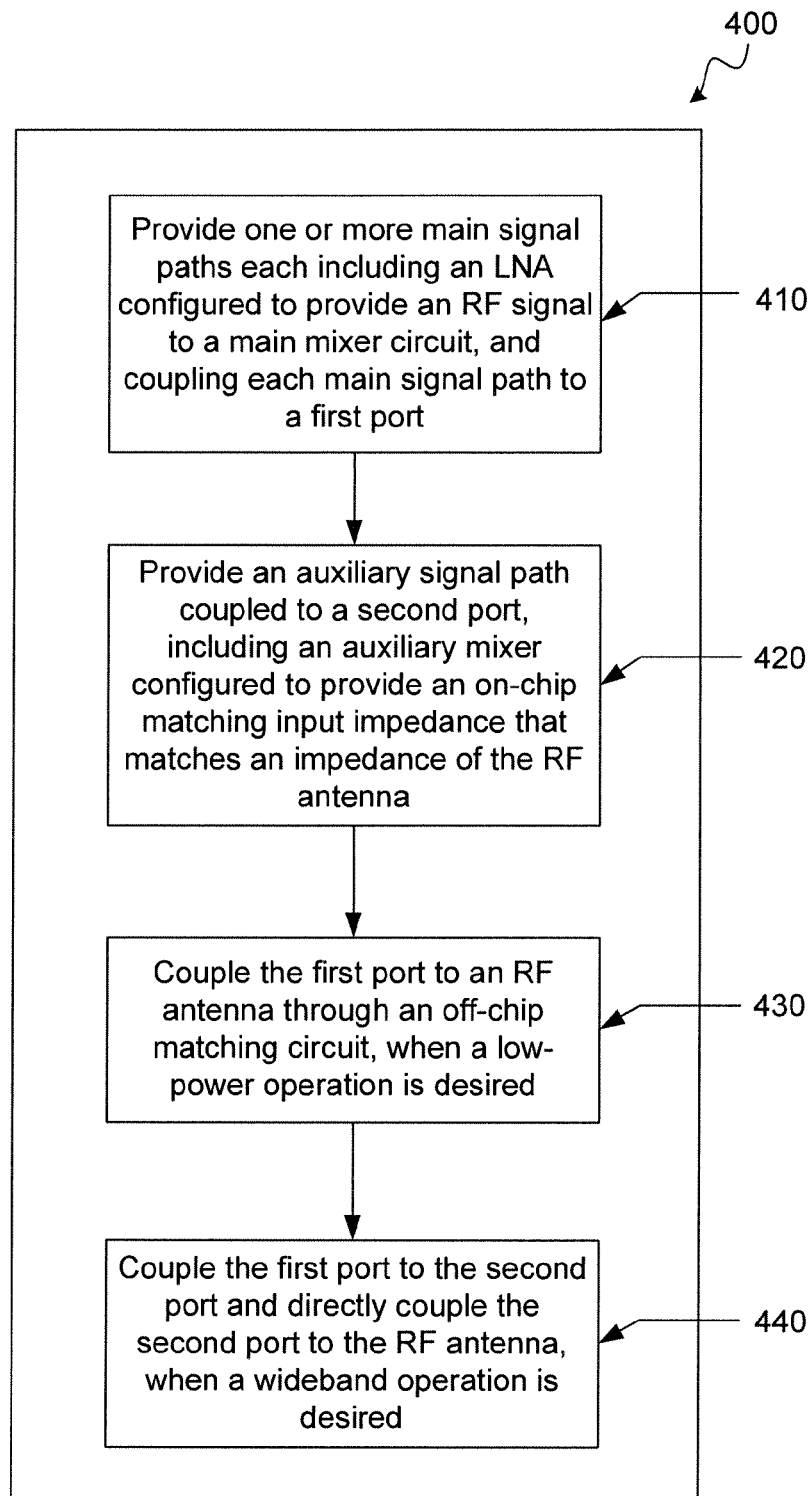


FIG. 3B

**FIG. 4**

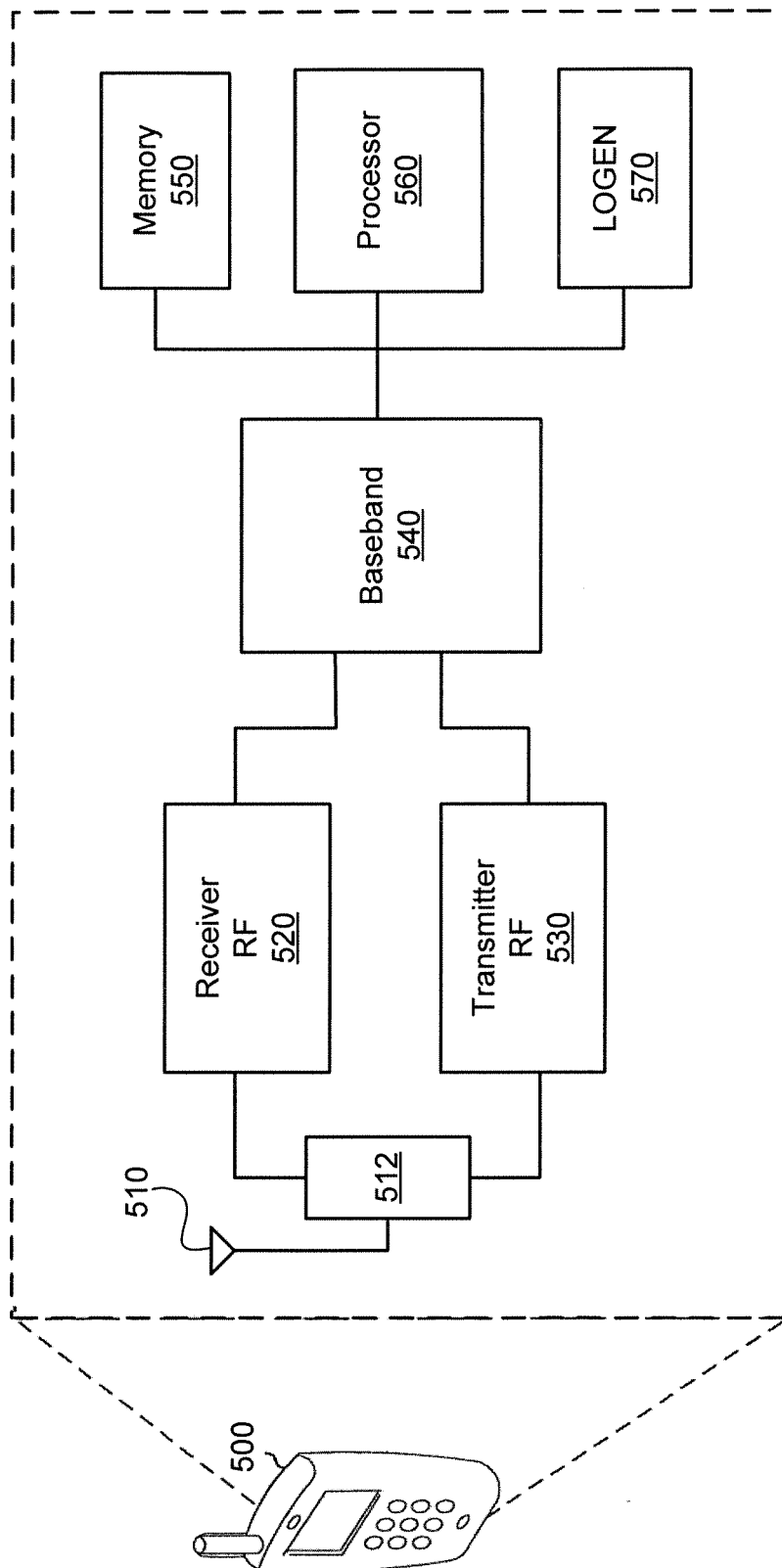


FIG. 5

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# RECEIVER ARCHITECTURE WITH RECONFIGURABLE ON-CHIP MATCHING FOR WIDEBAND OPERATION AND OFF-CHIP MATCHING FOR LOW-POWER OPERATION

## TECHNICAL FIELD

The present description relates generally to radio frequency (RF) communications, and more particularly, but not exclusively, to a receiver architecture with reconfigurable on-chip matching for wideband operation and off-chip matching for low-power operation.

## BACKGROUND

As the number of wireless standards and the range of frequencies of wireless communications continue to increase, there is an increasing need for communication receivers that are capable of handling multiple wireless standards spanning a wide range of frequencies. Also, as the number of wireless devices and the amount of wireless communications taking place increase, the communication receivers may have to be able to function satisfactorily in the presence of large amounts of noise and interference.

Further, the multitude of battery operated wireless devices has created a demand for extremely low-power transceivers to increase the handset talk time and to reduce the battery size and ultimately the cost. Meanwhile, the noise and linearity requirements are becoming more stringent to meet the quest for higher data rates with a highly congested spectrum. Typically, implementing low-noise receivers may become more challenging when the design objectives also include reconfigurable low-power consumption or wideband operation, and size reduction.

Therefore, the need exists for a low noise receiver that is reconfigurable for low-power or wideband operation, and can be implemented on a smaller chip area.

## BRIEF DESCRIPTION OF THE DRAWINGS

Certain features of the subject technology are set forth in the appended claims. However, for purpose of explanation, several embodiments of the subject technology are set forth in the following figures.

FIGS. 1A-1E illustrate examples of receiver architecture with configurable wideband and low-power operation in accordance with one or more implementations.

FIG. 2A-2B illustrate examples of low-noise amplifiers (LNAs) with and without inductor degeneration in accordance with one or more implementations.

FIG. 3A-3B illustrate examples of receiver circuits with and without LNA load inductor in accordance with one or more implementations.

FIG. 4 illustrates an example method for providing a receiver architecture with configurable wideband and low-power operation in accordance with one or more implementations.

FIG. 5 illustrates an example wireless communication device in accordance with one or more implementations.

## DETAILED DESCRIPTION

The detailed description set forth below is intended as a description of various configurations of the subject technology and is not intended to represent the only configurations in which the subject technology may be practiced. The

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appended drawings are incorporated herein and constitute a part of the detailed description. The detailed description includes specific details for the purpose of providing a thorough understanding of the subject technology. However, it will be clear and apparent to those skilled in the art that the subject technology is not limited to the specific details set forth herein and may be practiced using one or more implementations. In one or more instances, well-known structures and components are shown in block diagram form in order to avoid obscuring the concepts of the subject technology.

FIGS. 1A-1E illustrate examples of receiver architecture **100A** and **100B** with configurable low-power and wideband operation in accordance with one or more implementations of the subject technology. The receiver architecture **100A** may include one or more (e.g.,  $N$ , such as four) main signal paths **110** (e.g., **110-1** to **110-N**) coupled to first ports **130** (e.g., on-chip pins **130-1** to **130-N**) and an auxiliary signal path **120** coupled to a second port **140** provided on a chip **105**. The receiver architecture **100A** may include a multi-band receiver, and the main signal paths **110** may include signal paths corresponding to multiple frequency bands of the multi-band receiver. The auxiliary signal path **120** may provide an input impedance that can match an impedance of a radio-frequency (RF) antenna **160** (e.g.,  $50\Omega$ ) over a wide range of frequency. In one or more aspects of the subject technology, the main path may provide an output signal that can be used to reduce or cancel noise of the auxiliary signal path **120**.

The main signal paths **110** and the auxiliary path **120** may provide a configurable receiver architecture that can be configured for low-power or wideband operation. For example, in one or more implementations, one or more main signal paths **110** may be coupled through one or more off-chip matching circuits **150** (e.g., **150-1** to **150-N**) to the RF antenna **160** to provide a low-power receiver architecture (e.g., a cell phone receiver). In another implementation, the receiver architecture **100B** shown in FIG. 1B, may leverage the wideband impedance matching of the auxiliary signal path **120**, to replace the one or more off-chip matching circuits **150**. In the receiver architecture **100B**, one or more ports **130** may be connected (e.g., off-chip) to the port **140** and the RF antenna **160**. It is understood that the selection of the low-power or the wideband operation may be advantageously performed upon using the chip **105**. In other words, the chip **105** can be configured as a low power receiver or a wideband receiver by a user of the chip **105**. The low-power mode may be suitable for bands where an external off-chip filter is needed to filter the out of band blockers. In such configuration multiple RF ports (**130-1** to **130-N**) may be used to interface the receiver with multiple RF filters.

In one or more implementations, the off-chip matching circuit **150**, as shown in FIG. 1C, may include an LC circuit **100C** (e.g., an LC filter) including an inductor  $L$  (e.g., with inductance  $L$ ) and a capacitor  $C$  (e.g., with capacitance  $C$ ). The LC circuit **100C** may be provided externally, and values of  $L$  and  $C$  may be selected based on the frequency band of interest. The LC circuit **100C** may be configured to provide a matching resistive input impedance (e.g.,  $50\Omega$ ), when coupled to one or more main signal path **110**. It is understood that the off-chip matching circuit **150** may not be restricted to the LC circuit **100C**, and may be implemented by other circuits.

FIG. 1D illustrates an example circuit **100D** representing the main signal path **110** of FIGS. 1A and 1B in accordance with one or more implementations of the subject technology. The circuit **100D** may include a low-noise amplifier (LNA) **111**, such as a trans-conductance LNA that can provide a suitable gain at a low noise figure (e.g., 2 dB) for the RF signal received from the RF antenna **160** of FIGS. 1A and 1B. The



RF signal from the LNA 111 may be down-converted by a quadrature mixer formed by a in-phase (I) channel mixer 112 and a quadrature-phase (Q) channel mixer 114 to baseband signals (or an intermediate frequency (IF) signal, in heterodyne receiver architectures), provided to respective I and Q channel feedback trans-impedance amplifiers (TIAs) 116 and 118 (e.g., TIA buffers). The TIAs 116 and 118 may include resistors R1 and R2 in their respective feedback loops. The LNA, the quadrature mixer, and the TIA are known in the art and, for the sake of brevity, their description is skipped herein. It is understood that the main signal path 110 may not be restricted to the circuit 100D, and may be implemented by other circuits.

FIG. 1E illustrates an example circuit 100E representing the auxiliary signal path 120 of FIGS. 1A and 1B in accordance with one or more implementations of the subject technology. The circuit 100E may include I and Q channel mixers 122 and 124 and resistive feedback TIAs 126 and 128 with resistors R3 and R4 in their feedback loops. The circuit 100E may be combined by one or more main signal paths 110 (e.g., circuit 100D of FIG. 1D) to provide an input impedance  $R_i$  that matches the impedance of the antenna 160 of FIGS. 1A and 1B (e.g.,  $R_i=50\Omega$ ). Further, the output signals from the circuit 100E may be used to reduce or cancel the noise from the main signal path 110.

It is understood that the auxiliary signal path 120 may not be restricted to the circuit 100E, and may be implemented by other circuits. In one or more implementations, coupling of the circuit 100E to the one or more main signal paths 110 (e.g., circuit 100D) may be performed by one or more on-chip switches that can be operable by a user of the chip 105 of FIG. 1B. In other words, the user of the chip 105, instead of coupling one or more ports 130 to port 140 externally, may be able to make the coupling through closing the one or more on-chip switches.

FIG. 2A illustrates an example of a circuit 200A for a conventional LNA with inductor degeneration. An LNA circuit is typically a first block of a receiver circuit and it is known that the noise figure (NF) of the first stage dominates the overall NF of the receiver. Furthermore, maximum power transfer at input and output nodes of the LNA circuit can be achieved by matching the input impedance and output impedance of the LNA circuit with the impedance of the previous stage (e.g., the antenna, such as antenna 160 of FIG. 1A) and a next stage (e.g., coupling capacitor C and mixer 210).

One way to match the input resistance of the LNA circuit with the impedance of the antenna (e.g.,  $50\Omega$ ) may include the use of inductor degeneration. For example, in the LNA circuit 200A, inductor degeneration may be achieved by an inductor L1 coupled between the source node of an NMOS transistor T1 and ground potential. The input impedance of the LNA circuit 200A may be defined in terms of the values of the inductance L1, trans-conductance parameter (e.g.,  $g_m$ ) of transistor T1 and a gate-source capacitance ( $C_{GS}$ ) between the gate and source nodes of the transistor T1. Therefore, the impedance matching at the input of the LNA circuit 200A may be achieved by selection of suitable values for L1,  $g_m$ , and  $C_{GS}$ .

Further, in order to match the output impedance of the LNA circuit 200A to a load (e.g., coupling capacitor C and mixer 210) a load inductor L2 may be coupled between the drain node of the transistor T1 and a supply voltage  $V_{DD}$ . Creating inductors L1 and L2 on chip (e.g., on the chip 105 of FIG. 1A) may take a substantially large area. The disclosure herein may provide a circuit configuration where the input and output impedance matching can be performed without the use of the

inductors L1 and L2, therefore significantly reducing the area and power consumption of the LNA circuit.

FIG. 2B illustrates an example of an LNA circuit 200B without inductor degeneration in accordance with one or more implementations of the subject technology. The LNA circuit 200B includes a complementary inverter-based LNA, where the role of the inductors L1 and L2 of the LNA circuit 200A of FIG. 2A, in input and output impedance matching, can be advantageously performed by intrinsic and on-chip capacitances; thereby resulting in a significant saving in chip area and power consumption. The LNA circuit 200B includes a complementary MOS (CMOS) inverter formed by an NMOS transistor T1 and a PMOS transistor T2. The complementary configuration may support a reduction of approximately 50% in power consumption. This is because the LNA circuit 200B can benefit from the gains corresponding to both NMOS and PMOS stages, which can be viewed as two common-source amplifier stages coupled together. Stated differently, the LNA circuit 200B can provide the same output signal power, as compared to a single transistor LNA (e.g., LNA circuit 200A) with approximately 50% lower bias current.

The chip area reduction is the result of replacement of on-chip inductors L1 and L2 of the LNA circuit 200A. In the proposed LNA circuit 200B, the input impedance matching may be performed by the intrinsic gate-drain capacitance  $C_{gd}$  of the transistors T1 and T2. In one or more implementations, an additional on-chip capacitor C1 may be used, which can be added to the intrinsic capacitance  $C_{gd}$  via an on-chip switch S. The role of the capacitance  $C_{gd}$  as a drain-to-gate feedback capacitance in the input impedance of the LNA circuit 200B is determined by the Miller-effect of the capacitance  $C_{gd}$  (and C1). The Miller effect may result in a Miller input impedance by bringing a portion of the output impedance (e.g., the impedance seen from the gate nodes of transistors T1 and T2) to the input port (e.g., gate node of the transistors T1 and T2) of the LNA circuit 200B. The Miller input impedance and the Miller output impedance (e.g., the effective impedance seen from the drain nodes of transistors T1 and T2) may depend on parameters of the transistors T1 and T2, for example, the trans-conductance parameter (e.g.,  $g_m$ ) and the gate-drain parasitic capacitance  $C_{gd}$ , both of which can be adjusted by design. Therefore, the values of  $C_{gd}$  and  $g_m$  of transistor T1 and T2 may be adjusted (for example, by suitable design of the size and the gate-drain junctions of transistors T1 and T2) to provide a desired input impedance  $R_i$  (e.g.,  $50\Omega$ ) at the input of the LNA circuit 200B and a desired output impedance  $R_o$  at the output node (e.g., drain nodes of T1 and T2) of the LNA circuit 200B, without using the inductors L1 and L2 of LNA circuit 200A. The additional on-chip capacitor C1 may be added, as needed, via the switch S, to boost the effect of the intrinsic capacitance  $C_{gd}$  for further adjustments. Further, the use of a programmable variable capacitance C1 may provide a tunable matching which can be programmable.

FIG. 3A illustrates an example of a conventional receiver circuit 300A with an LNA load inductor L1. The receiver circuit 300A includes an LNA 320 such as a trans-conductance LNA, I and Q channel mixer circuits 310 and 315, and feedback TIAs 330 and 335 with resistors R1 and R2 in their respective feedback loops. Also included in the LNA circuit 300A are an inductor load L (e.g., having an inductance L) and a capacitor C (e.g., having a capacitance C). The capacitor C may include an equivalent capacitance seen at node 308 (e.g., an input capacitance of the mixer circuits 310 and 315 in parallel with the output capacitance of LNA 320), which can be tuned with a suitable value for the inductance L, for a frequency corresponding to a desired frequency band.

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FIG. 3B illustrates an example of a receiver circuit **300B** without the LNA load inductor **L** of the receiver circuit **300A** of FIG. 3A in accordance with one or more implementations of the subject technology. In the receiver circuit **300B**, the LNA **320**, I and Q channel mixers **310** and **315**, feedback TIAs **330** and **335**, and feedback resistors **R1** and **R2** are the same as in the receiver circuit **300A** of FIG. 3A. In the receiver circuit **300B**, the role of the bulky inductor **L** is played by first and second cross-coupling resistors **R3** and **R4** that cross couple TIAs **330** and **335**. The first cross coupled-resistor **R3** may be coupled between an input node **312** of the TIA **330** and an output node **318** of the TIA **335**, and the second cross coupled-resistor **R4** may be coupled between an input node **314** of the TIA **335** and an output node **316** of the TIA **330**.

The cross-coupled resistors **R3** and **R4** may contribute to complex input impedances seen from nodes **312** and **314**, which once up-converted and seen from node **322** can be viewed as an effective inductive impedance (e.g.,  $jx$ , with a positive imaginary portion  $x$ ). The values of the resistances **R3** and **R4** can be adjusted so that the effective inductive impedance at node **322** can be tuned to the equivalent capacitance **C** seen at node **308** of FIG. 3A. For example, the resistances **R3** and **R4** may be variable resistances and by adjusting the value of the variable resistances **R3** and **R4**, tuning to frequencies corresponding to multiple frequency bands of the receiver **300B** can be performed. It is understood that in the receiver circuit **300A**, tuning to the multiple frequency bands may involve using multiple load inductors with different inductance values. Therefore, the present disclosure provides a substantial chip-area reduction by replacing the role of the multiple load inductors with two variable resistors (e.g., **R3** and **R4**).

FIG. 4 illustrates an example method **400** for providing a receiver architecture with configurable wideband and low-power operation in accordance with one or more implementations of the subject technology. For explanatory purposes, the example method **400** is described herein with reference to the low-power receiver architecture **100A** of FIG. 1A, the wideband receiver architecture **100B** of FIG. 1B, the circuit **100D** of FIG. 1D, and the circuit **100E** of FIG. 1E; however, the example method **400** is not limited to the low-power receiver Architecture **100A**, wideband receiver architecture **100B**, the circuit **100D**, and the circuit **100E**. Further for explanatory purposes, the blocks of the example method **400** are described herein as occurring in serial, or linearly. However, multiple blocks of the example method **400** may occur in parallel. In addition, the blocks of the example method **400** need not be performed in the order shown and/or one or more of the blocks of the example method **400** need not be performed.

At operation block **410**, one or more main signal paths **110** may be provided. Each main signal path (e.g., **110** of FIGS. 1A and 1B and **100D** of FIG. 1D) may include a low-noise amplifier (LNA) (e.g., **111** of FIG. 1D) configured to provide a radio frequency (RF) signal to a main mixer circuit (e.g., a quadrature mixer formed by I and Q channel mixers **112** and **114** of FIG. 1D). Each main signal path may be coupled to a first port (e.g., **130** of FIG. 1A). At operation block **420**, an auxiliary signal path (e.g., **120** of FIGS. 1A and 1B and **100E** of FIG. 1E) may be provided and coupled to a second port (e.g., **140** of FIGS. 1A and 1B). The auxiliary signal path may include an auxiliary mixer (e.g., a quadrature mixer formed by I and Q channel mixers **122** and **124** of FIG. 1E) that may be configured to provide an on-chip matching input impedance (e.g.,  $R_i$  of FIG. 1E) that can match an impedance of the RF antenna (e.g., **160** of FIGS. 1A and 1B). The first port may

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be coupled to the RF antenna through an off-chip matching circuit **150**, when a low-power operation is desired (operation block **430**). At operation block **440**, the first port may be coupled to the second port and the second port may be directly coupled to the RF antenna, when a wideband operation is desired.

In one or more implementation, the receiver architecture with configurable wideband and low-power operation of FIGS. 1A and 1B may be realized in a wireless communication device described below.

FIG. 5 illustrates an example wireless communication device **500** in accordance with one or more implementations of the subject technology. The wireless communication device **500** may comprise a radio-frequency (RF) antenna **510**, a receiver **520**, a transmitter **530**, a baseband processing module **540**, a memory **550**, a processor **560**, and a local oscillator generator (LOGEN) **570**. In various embodiments of the subject technology, one or more of the blocks represented in FIG. 5 may be integrated on one or more semiconductor substrates. For example, the blocks **520-570** may be realized in a single chip or a single system on chip, or may be realized in a multi-chip chipset.

The RF antenna **510** may be suitable for transmitting and/or receiving RF signals (e.g., wireless signals) over a wide range of frequencies. Although a single RF antenna **510** is illustrated, the subject technology is not so limited.

The receiver **520** may comprise suitable logic circuitry and/or code that may be operable to receive and process signals from the RF antenna **510**. The receiver **520** may, for example, be operable to amplify and/or down-convert received wireless signals. In various embodiments of the subject technology, the receiver **520** may be operable to cancel noise in received signals and may be linear over a wide range of frequencies. In this manner, the receiver **520** may be suitable for receiving signals in accordance with a variety of wireless standards. Wi-Fi, WiMAX, Bluetooth, and various cellular standards. In various embodiments of the subject technology, the receiver **520** may not require any SAW filters and few or no off-chip discrete components such as large capacitors and inductors.

The transmitter **530** may comprise suitable logic circuitry and/or code that may be operable to process and transmit signals from the RF antenna **510**. The transmitter **530** may, for example, be operable to up-convert baseband signals to RF signals and amplify RF signals. In various embodiments of the subject technology, the transmitter **530** may be operable to up-convert and amplify baseband signals processed in accordance with a variety of wireless standards. Examples of such standards may include Wi-Fi, WiMAX, Bluetooth, and various cellular standards. In various embodiments of the subject technology, the transmitter **530** may be operable to provide signals for further amplification by one or more power amplifiers.

The duplexer **512** may provide isolation in the transmit band to avoid saturation of the receiver **520** or damaging parts of the receiver **520**, and to relax one or more design requirements of the receiver **520**. Furthermore, the duplexer **512** may attenuate the noise in the receive band. The duplexer may be operable in multiple frequency bands of various wireless standards.

The baseband processing module **540** may comprise suitable logic, circuitry, interfaces, and/or code that may be operable to perform processing of baseband signals. The baseband processing module **540** may, for example, analyze received signals and generate control and/or feedback signals for configuring various components of the wireless communication device **500** such as the receiver **520**. The baseband processing

module **540** may be operable to encode, decode, transcode, modulate, demodulate, encrypt, decrypt, scramble, descramble, and/or otherwise process data in accordance with one or more wireless standards.

The processor **560** may comprise suitable logic, circuitry, and/or code that may enable processing data and/or controlling operations of the wireless communication device **500**. In this regard, the processor **560** may be enabled to provide control signals to various other portions of the wireless communication device **500**. The processor **560** may also control transfers of data between various portions of the wireless communication device **500**. Additionally, the processor **560** may enable implementation of an operating system or otherwise execute code to manage operations of the wireless communication device **500**.

The memory **550** may comprise suitable logic, circuitry, and/or code that may enable storage of various types of information such as received data, generated data, code, and/or configuration information. The memory **550** may comprise, for example, RAM, ROM, flash, and/or magnetic storage. In various embodiment of the subject technology, information stored in the memory **550** may be utilized for configuring the receiver **520** and/or the baseband processing module **540**.

The local oscillator generator (LOG EN) **570** may comprise suitable logic, circuitry, interfaces, and/or code that may be operable to generate one or more oscillating signals of one or more frequencies. The LOG EN **570** may be operable to generate digital and/or analog signals. In this manner, the LOG EN **570** may be operable to generate one or more clock signals and/or sinusoidal signals. Characteristics of the oscillating signals such as the frequency and duty cycle may be determined based on one or more control signals from, for example, the processor **560** and/or the baseband processing module **540**.

In operation, the processor **560** may configure the various components of the wireless communication device **500** based on a wireless standard according to which it is desired to receive signals. Wireless signals may be received via the RF antenna **510** and amplified and down-converted by the receiver **520**. The baseband processing module **540** may perform noise estimation and/or noise cancellation, decoding, and/or demodulation of the baseband signals. In this manner, information in the received signal may be recovered and utilized appropriately. For example, the information may be audio and/or video to be presented to a user of the wireless communication device, data to be stored to the memory **550**, and/or information affecting and/or enabling operation of the wireless communication device **500**. The baseband processing module **540** may modulate, encode and perform other processing on audio, video, and/or control signals to be transmitted by the transmitter **530** in accordance with various wireless standards.

Those of skill in the art would appreciate that the various illustrative blocks, modules, elements, components, and methods described herein may be implemented as electronic hardware, computer software, or combinations of both. To illustrate this interchangeability of hardware and software, various illustrative blocks, modules, elements, components, and methods have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application. Various components and blocks may be arranged differently (e.g.,

arranged in a different order, or partitioned in a different way) all without departing from the scope of the subject technology.

As used herein, the phrase “at least one of” preceding a series of items, with the term “and” or “or” to separate any of the items, modifies the list as a whole, rather than each member of the list (i.e., each item). The phrase “at least one of” does not require selection of at least one of each item listed; rather, the phrase allows a meaning that includes at least one of any one of the items, and/or at least one of any combination of the items, and/or at least one of each of the items. By way of example, the phrases “at least one of A, B, and C” or “at least one of A, B, or C” each refer to only A, only B, or only C; any combination of A, B, and C; and/or at least one of each of A, B, and C.

A phrase such as “an aspect” does not imply that such aspect is essential to the subject technology or that such aspect applies to all configurations of the subject technology. A disclosure relating to an aspect may apply to all configurations, or one or more configurations. An aspect may provide one or more examples of the disclosure. A phrase such as an “aspect” may refer to one or more aspects and vice versa. A phrase such as an “embodiment” does not imply that such embodiment is essential to the subject technology or that such embodiment applies to all configurations of the subject technology. A disclosure relating to an embodiment may apply to all embodiments, or one or more embodiments. An embodiment may provide one or more examples of the disclosure. A phrase such as an “embodiment” may refer to one or more embodiments and vice versa. A phrase such as a “configuration” does not imply that such configuration is essential to the subject technology or that such configuration applies to all configurations of the subject technology. A disclosure relating to a configuration may apply to all configurations, or one or more configurations. A configuration may provide one or more examples of the disclosure. A phrase such as a “configuration” may refer to one or more configurations and vice versa.

The word “exemplary” is used herein to mean “serving as an example, instance, or illustration.” Any embodiment described herein as “exemplary” or as an “example” is not necessarily to be construed as preferred or advantageous over other embodiments. Furthermore, to the extent that the term “include,” “have,” or the like is used in the description or the claims, such term is intended to be inclusive in a manner similar to the term “comprise” as “comprise” is interpreted when employed as a transitional word in a claim.

All structural and functional equivalents to the elements of the various aspects described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 U.S.C. §112, sixth paragraph, unless the element is expressly recited using the phrase “means for” or, in the case of a method claim, the element is recited using the phrase “step for.”

The previous description is provided to enable any person skilled in the art to practice the various aspects described herein. Various modifications to these aspects will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other aspects. Thus, the claims are not intended to be limited to the aspects shown herein, but are to be accorded the full scope consistent with the language claims, wherein reference to an element in the

singular is not intended to mean “one and only one” unless specifically so stated, but rather “one or more.” Unless specifically stated otherwise, the term “some” refers to one or more. Pronouns in the masculine (e.g., his) include the feminine and neuter gender (e.g., her and its) and vice versa. Headings and subheadings, if any, are used for convenience only and do not limit the subject disclosure.

What is claimed is:

1. A circuit for a receiver with reconfigurable low-power or wideband operation, the circuit comprising:

one or more main signal paths each coupled to a first port and including a low-noise amplifier (LNA) configured to provide a radio frequency (RF) signal to a main mixer circuit; and

an auxiliary signal path coupled to a second port, the auxiliary signal path including an auxiliary mixer configured to provide an on-chip matching input impedance, wherein:

- a) the first port is coupled to an RF antenna through an off-chip matching circuit, when a low-power operation is desired, and
- b) the first port is coupled to the second port and to the RF antenna, when a wideband operation is desired,
- c) the matching input impedance matches an impedance of the antenna, and
- d) the main mixer comprises a quadrature mixer and is configured to convert the RF signal to a baseband signal.

2. The circuit of claim 1, wherein the receiver is a multi-band receiver and each main signal path is coupled via a respective first port and through a respective off-chip matching circuit to the RF antenna, when the low-power operation is desired, and wherein the respective off-chip matching circuit is associated with a frequency band.

3. The circuit of claim 1, wherein the quadrature mixer and the TIA are configured to operate in a differential mode.

4. The circuit of claim 1, wherein the auxiliary mixer comprises a quadrature mixer and is coupled to a trans-impedance amplifier (TIA), and wherein the quadrature mixer and the TIA are configured to operate in a differential mode.

5. The circuit of claim 1, wherein the receiver circuit is implemented on a chip with one or first ports for the low-power operation and at least one port for the wideband operation.

6. The circuit of claim 1, wherein:

- a) the LNA comprises an inverter-based LNA with no degeneration inductors,
- b) impedance matching is provided through one or more feedback capacitances, and
- c) impedance matching comprises tunable matching and is provided through one or more programmable feedback capacitances.

7. The circuit of claim 6, wherein:

- a) the LNA is a complementary inverter-based LNA,
- b) the feedback capacitance is provided by a parasitic capacitance,
- c) the parasitic capacitance comprises at least one of a parasitic gate-drain capacitance of NMOS or PMOS transistors of the complementary inverter-based LNA,
- d) the feedback capacitance is further provided by at least one additional on-chip capacitance,
- e) the additional on-chip capacitance is parallel to the parasitic gate-drain capacitances, and
- f) the inverter-based LNA is implemented on a substantially smaller area and is configured to consume approximately 50% less power, as compared to an inductor degenerated LNA.

8. The circuit of claim 1, wherein:

- a) at least one of the main mixer or the auxiliary mixer comprises a quadrature passive mixer coupled to a first and a second trans-impedance amplifiers (TIAs),
- b) input and output nodes of the first and the second TIAs are cross-coupled via a first and a second resistor, and
- c) the cross coupling is configured to create a complex impedance that replaces one or more LNA load inductors.

9. The circuit of claim 8, wherein:

- a) the input and out nodes of the first TIA are coupled to output and input nodes of the second TIA, via the first and the second resistors, respectively,
- b) the created complex impedance is configured to replace one or more LNA load inductors corresponding to one or more frequency bands of the receiver, and
- c) the replacement of the one or more LNA load inductors by the created complex impedance results in substantial chip area reduction.

10. A method for providing a receiver with reconfigurable low-power or wideband operation, the method comprising:

providing one or more main signal paths each including a low-noise amplifier (LNA) configured to provide a radio frequency (RF) signal to a main mixer circuit, and coupling each main signal path to a first port;

providing an auxiliary signal path coupled to a second port, the auxiliary signal path including an auxiliary mixer configured to provide an on-chip matching input impedance that matches an impedance of an RF antenna;

coupling the first port to the RF antenna through an off-chip matching circuit, when a low-power operation is desired; and

coupling the first port to the second port and to the RF antenna, when a wideband operation is desired, wherein the main mixer comprises a quadrature mixer and is configured to convert the RF signal to a baseband signal.

11. The method of claim 10, wherein the receiver is a multi-band receiver and the method further comprises coupling, when the low-power operation is desired, each main signal path via a respective first port and through a respective off-chip matching circuit to the RF antenna, and wherein the respective off-chip matching circuit is associated with a frequency band.

12. The method of claim 10, wherein the quadrature mixer and the TIA are configured to operate in a differential mode.

13. The method of claim 10, wherein the auxiliary mixer comprises a quadrature mixer and is coupled to a trans-impedance amplifier (TIA), and wherein the quadrature mixer and the TIA are configured to operate in a differential mode.

14. The method of claim 10, wherein the receiver circuit is implemented on a chip with one or first ports for the low-power operation and at least one port for the wideband operation.

15. The method of claim 10, wherein providing the one or more main signal paths comprises providing the one or more main signal paths that include an inverter-based LNA with no degeneration inductors, and providing impedance matching through one or more feedback capacitances, and wherein the impedance matching comprises tunable matching and is provided through one or more programmable feedback capacitances.

16. The method of claim 15, wherein:

- a) the LNA is a complementary inverter-based LNA,
- b) providing the impedance matching is through one or more feedback capacitances that include a parasitic capacitance including at least one of a parasitic gate-

drain capacitance of NMOS or PMOS transistors of the complementary inverter-based LNA,

- c) providing the impedance matching further comprises providing at least one additional on-chip capacitance parallel to the parasitic gate-drain capacitances, and 5
- d) the inverter-based LNA is implemented on a substantially smaller area and is configured to consume approximately 50% less power, as compared to an inductor degenerated LNA.

**17.** The method of claim **10**, wherein: 10

- a) at least one of the main mixer or the auxiliary mixer comprises a quadrature passive mixer coupled to a first and a second trans-impedance amplifiers (TIAs),
- b) input and output nodes of the first and the second TIAs are cross-coupled via a first and a second resistor, and 15
- c) the cross coupling is configured to create a complex impedance that replaces one or more LNA load inductors.

**18.** The method of claim **17**, wherein:

- a) the input and out nodes of the first TIA are coupled to output and input nodes of the second TIA, via the first and the second resistors, respectively, 20
- b) the created complex impedance is configured to replace one or more LNA load inductors corresponding to one or more frequency bands of the receiver, and 25
- c) the replacement of the one or more LNA load inductors by the created complex impedance results in substantial chip area reduction.

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